Requirements, Goals and Challenges for an X-Ray Microcalorimeter Spectrometer on the Constellation-X Observatory

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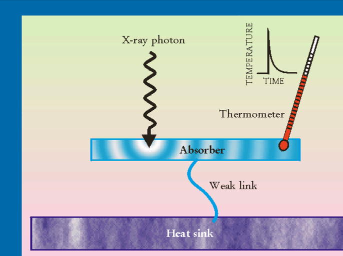
X-Ray Microcalorimeters:

Measuring energy by the thermalization of individual photons.



Integrated Product Development Team founded in 1998 in response to NRA:

Five groups selected for initial period of R&D funding:

Goddard, NIST and SAO - A comprehensive approach for developing microcalorimeters. Implanted Si, TES, and NTD Ge.

Stanford University - Tungsten Transition-Edge Sensors for Constellation Soft X-Ray Detector with Ge absorbers

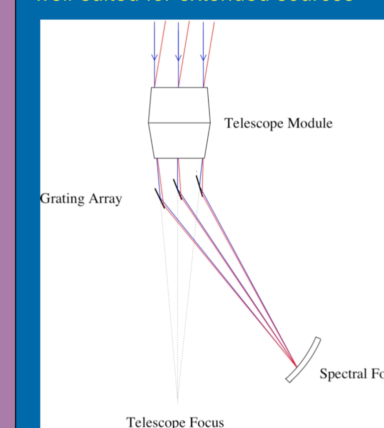
Lawrence Livermore National Lab - High resolution X-ray microcalorimeter detectors with multilayer absorbers and multilayer transition-edge sensors

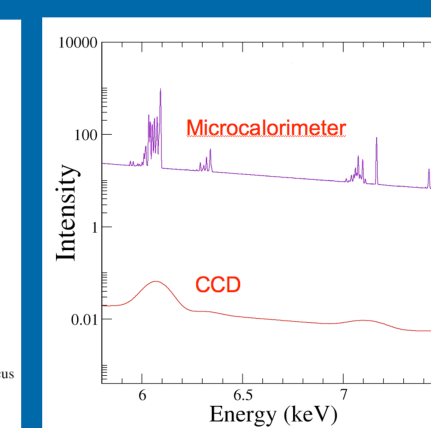
XMS Performance Requirement		Trace to Top-Level Mission Requirements
Bandpass	0.6 – 10 keV	TLRD
Spectral resolving power (E/ΔE)	1500 at 6 keV	TLRD
Angular resolution	5 arcsec	Oversample SXT PSF by a factor of 3
Field of view	2.5 arcmin	TLRD
Derived Detector Requirements		**Derivation**
Pixel size	242 μm	Meets TLRD beam sampling requirement
Number of pixels	32 x 32	Gives 2.7 arcmin FOV vs. 2.5 arcmin requirement
Energy resolution	4 eV at 6 keV; 2 eV at 1 keV	Gives E/ΔE = 1500 at 6 keV
Intrinsic quantum efficiency	95%	Flowdown to meet effective area req.
Filling Factor	95%	Flowdown to meet effective area req.
Detector speed	<300 μsec pulse decay time constant	Supports bright source counting rate req.
Time resolution	10 μsec	Allocation to meet absolute timing req.
Derived Instrument Requirements		**Derivation**
Mass	147 kg	Current engineering estimate
Power (watts)	80/146 (min/max) 150/200 (BOL/EOL)	For analog, digital, CADR control electronics Cryocooler electronics
Data rate (avg/peak)	7.2/640 kbps	Average source rate plus 840 bps H/K data Peak rate from bright sources limit

New capability created by x–ray microcalorimeter

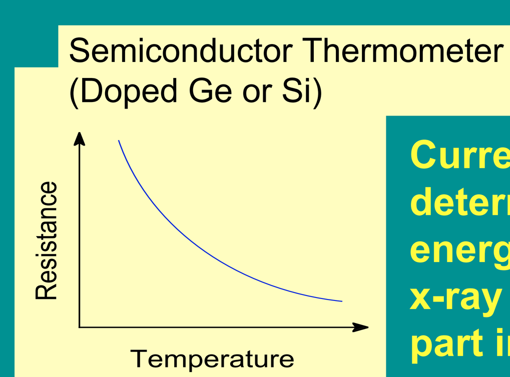
Energy resolution of gratings degrades with increasing energy and they are not well-suited for extended sources

X-ray CCDs are great for imaging but have low spectral resolution

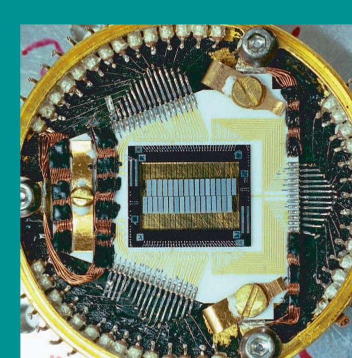




Constellation-X Microcalorimeter Technology



Currently can determine the energy of a single x-ray photon to a part in 2000!

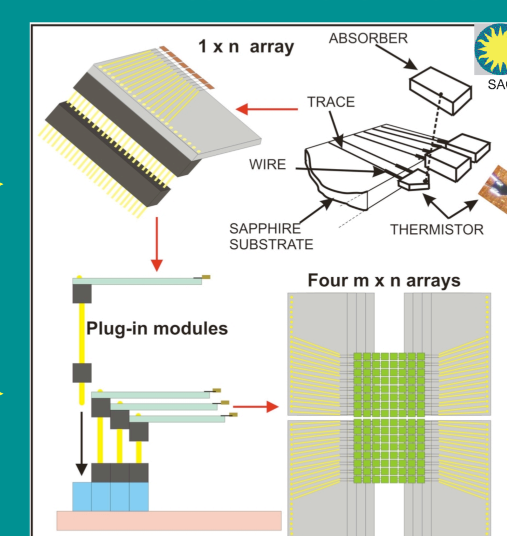


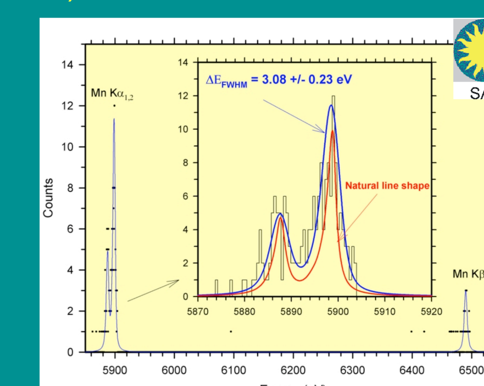
First x-ray microcalorimeter in space (1995.) Brief suborbital flight produced spectrum of soft x-ray background

Neutron Transmutation-Doped (NTD) Ge Microcalorimeters

Each linear array module is fitted with a miniature connector attached to the bottom of the sapphire substrate through which the electrical signals are fed .

Each module is inserted into a mating connector mounted into a *quadrant base*. A two-dimensional array can be built up from a series of these stacked linear arrays.

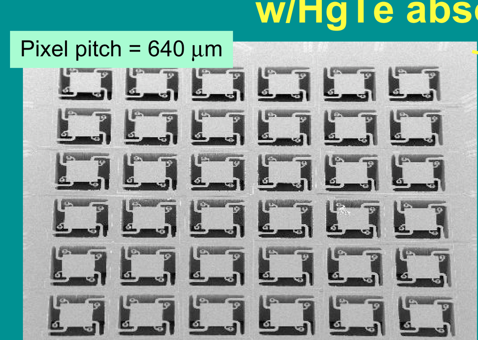


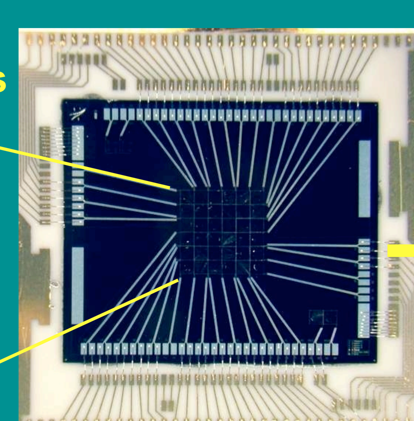


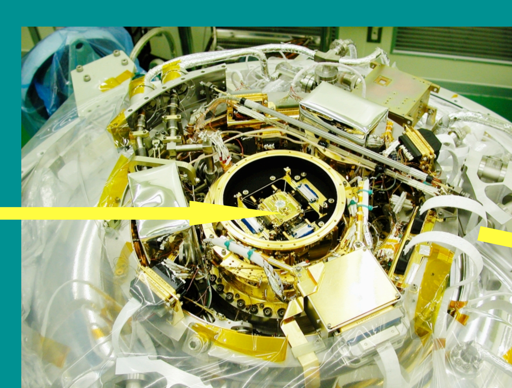
0.35 mm x 0.35 mm x 7 μm tin absorber + NTD 17 Ge thermistor

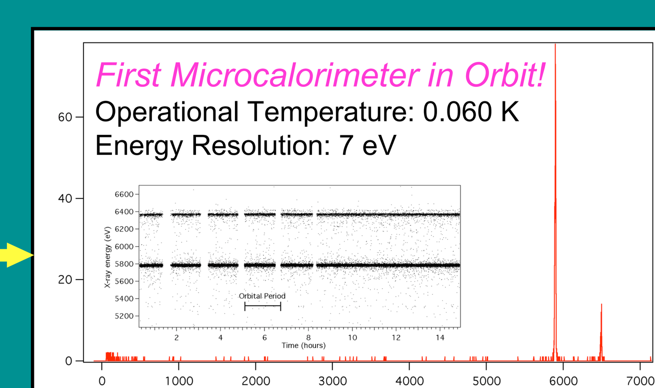
(E. Silver et al.)

Ion-implanted Si w/HgTe absorbers

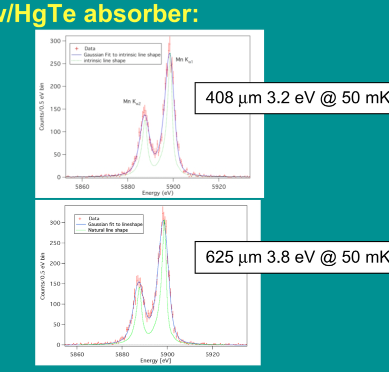




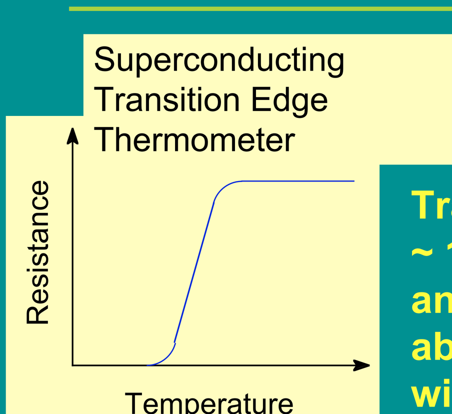




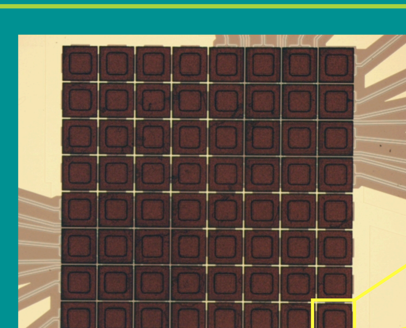
State of the art for ion-implanted Si w/HgTe absorber:



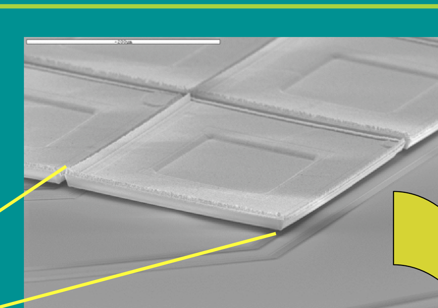
Modeling predicts 2.5 eV; appear to be limited by thermal fluctuations of x-rays absorbed in frame



Transition at ~ 100 mK and only about 1 mK wide.

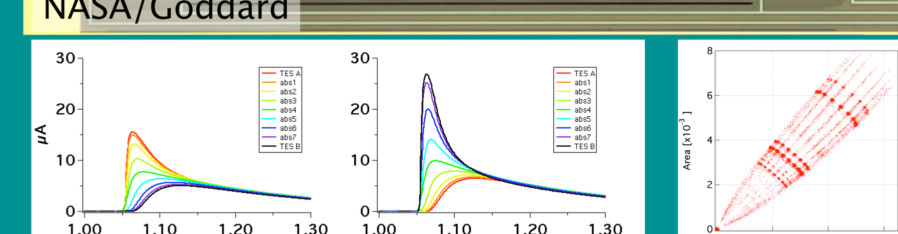


8 x 8 array of identical TES devices

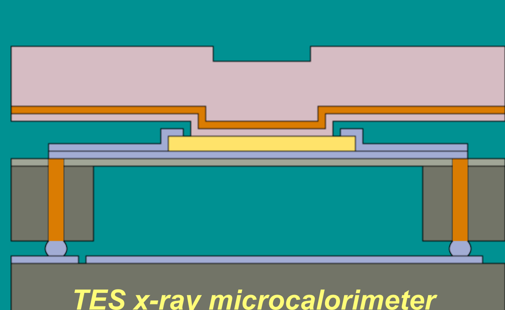


Integral, overhanging absorbers (Bi) to achieve high filling factor

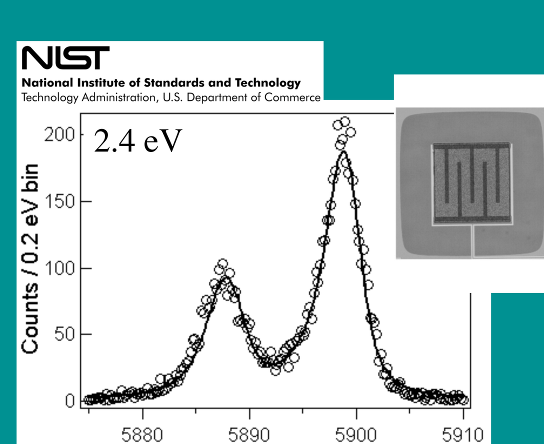
Position-Sensitive TES: two TESs connected to segmented absorber

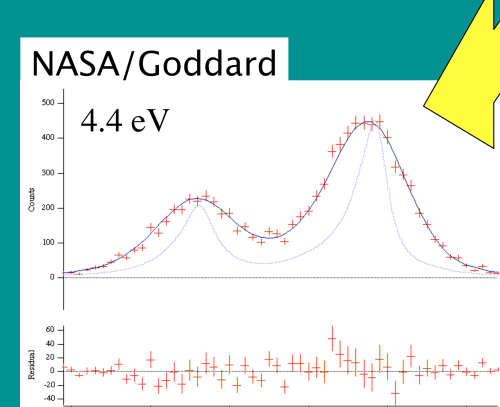


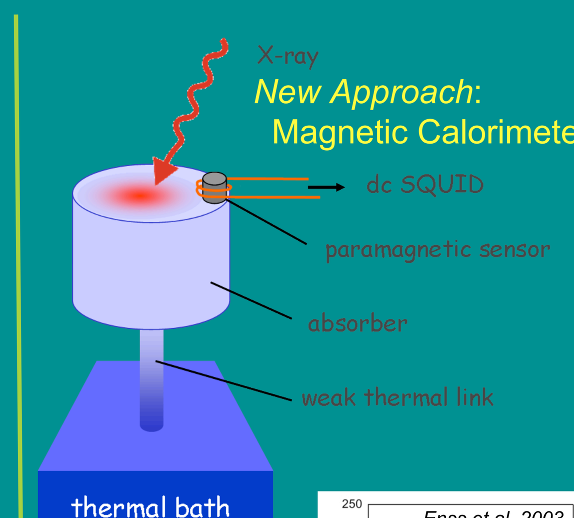
Thermal diffusion gives rise to different pulse responses and hence position; summing signals gives x-ray energy.



TES x-ray microcalorimeter

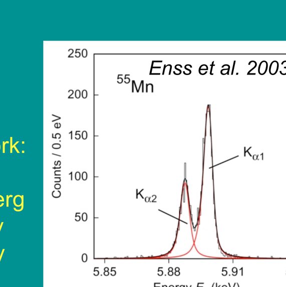






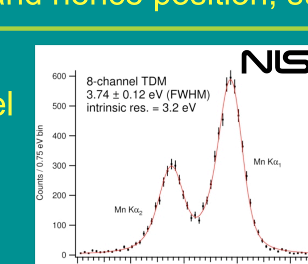
New Approach: Magnetic Calorimeter

Large consortium at work:
- Brown University
- University of Heidelberg
- IPHT, Jena, Germany
- PTB, Berlin, Germany
- SAO
- Goddard
- NIST

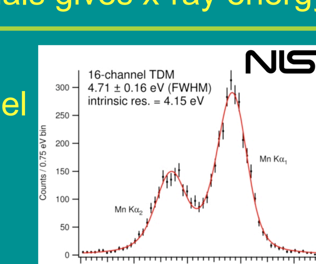


energy resolution 3.4 eV

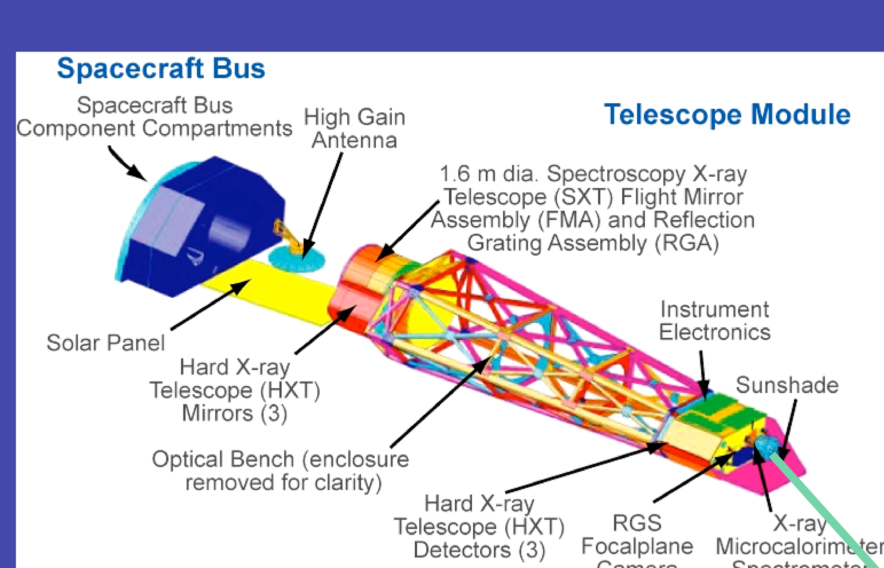
8 Channel MUX



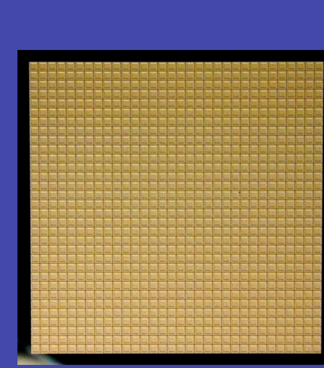
16 Channel MUX



Constellation-X Cooling Technologies



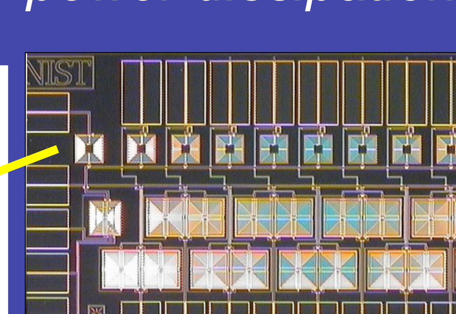
1000 pixel array

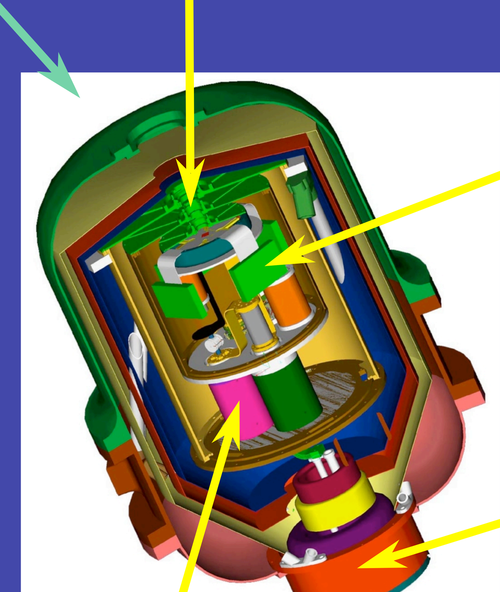


Technology Readiness Reference Design:

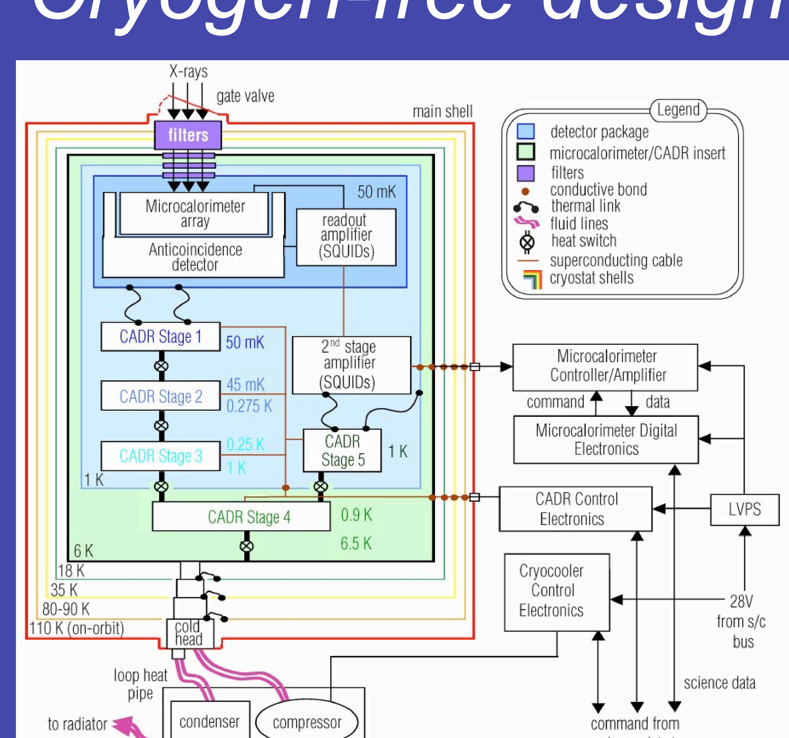
- 32 x 32 TES microcalorimeter array
- MUX SQUID readout
- Continuous ADR
- Cryocoolers

Multiplexed SQUID readout: enables larger arrays and low power dissipation





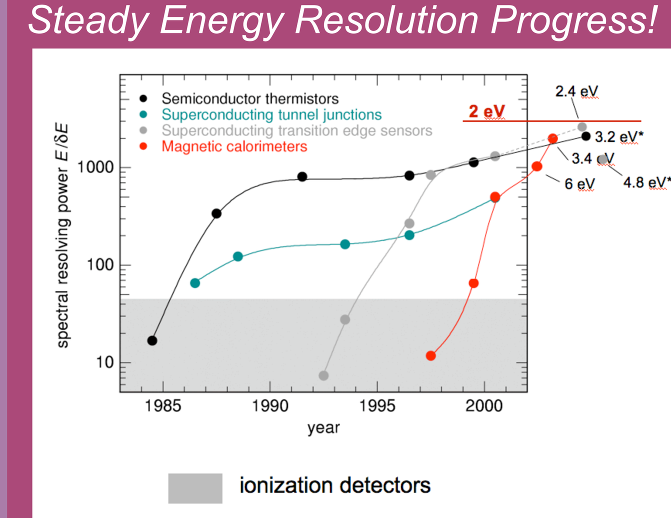
Cryogen-free design



Cryocooler

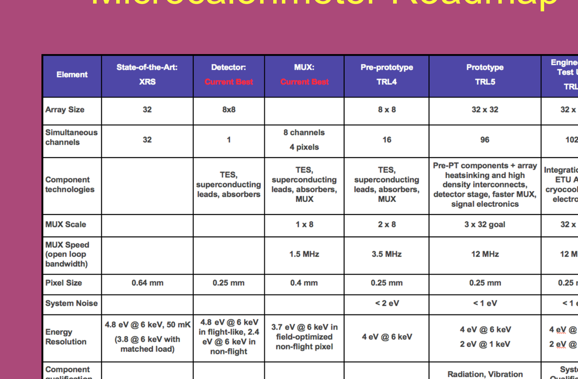
Multi-stage ADRs

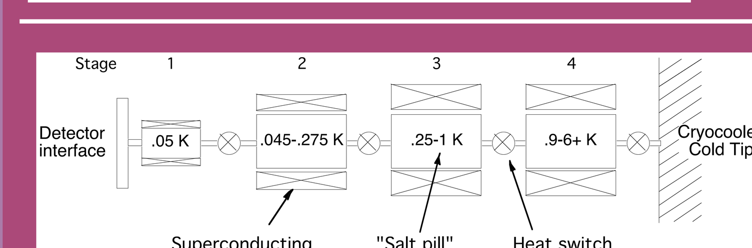
Steady Energy Resolution Progress!



* These devices meet Con-X requirements for quantum efficiency

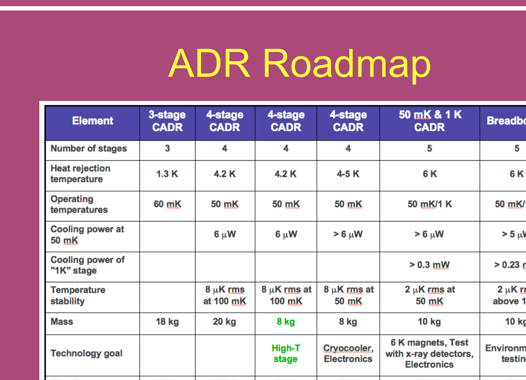
Microcalorimeter Roadmap





Cooling Stage	Temperature	Cooling Power	Temperature Stability	Heat Rejection Temperature
Detectors, 1st stage SQUIDs	50 mK	5 μW	2 μK rms	6 K
2nd stage SQUIDs	1 K (TBR)	230 μW	TBD	

ADR Roadmap



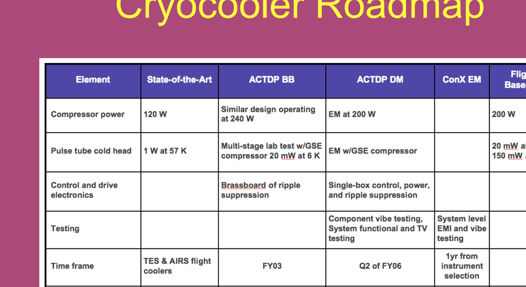
Cryocooler development needed for next generation space-based observatories
- 4-6 K/18 K two-stage cooling
- Remote coldheads (on deployable structures)
- Minimal generated noise (EMI and vibration)

Solution was the Advanced Cryocooler Technology Development Program (ACTDP)

ACTDP requirements driven by three missions
- James Webb Space Telescope
- Terrestrial Planet Finder
- Constellation-X

Program designed to provide proven Develepment Model (DM) coolers in 2006

Cryocooler Roadmap



ACTDP
- Originally funded through TPF, then by TPF, but joint program with Constellation-X and JWST
- JWST now funding
- All three coolers at TRL-5 by March '06 downselect

Constellation-X
- One year from instrument selection to TRL-6
- Integrate with EM Microcalorimeter and ADR in cryostat => EM XMS